Multimeasurement streamer acquisition for reservoir development – A case study from offshore West Africa

Chris Cunnell®, WesternGeco; Stephen McHugo, Shona Joyce, Phil Bennett and Andrew Furber, Schlumberger; Muharrem Boztas, BOZ

Summary

A towed-streamer seismic survey was acquired offshore West Africa using a multimeasurement acquisition system. The objective of the new 3D seismic survey was to acquire high-quality, high-resolution 3D seismic data to improve confidence in siting appraisal and development wells above that given by existing legacy 2D data. Analysis and preliminary interpretation of the processed data volumes show that the data set achieved the characteristics of broadband seismic data required for detailed structural and stratigraphic interpretation, with receiver-side deghosting benefiting from a flat, deep streamer tow configuration and contribution from velocity data - derived from the accelerometer measurements for frequencies below 10Hz.

Introduction

In recent years, a number of both acquisition and/or processing solutions were developed to provide broadband marine data from towed streamers, with a focus on extending the temporal bandwidth at both low and high ends of the spectrum. Techniques to attenuate the receiver-side ghost include variable-depth streamers (Soubaras and Lafet, 2013) that exploit notch diversity caused by non-uniform tow depths at different offsets, as well as streamers that combine multimeasurements – typically total pressure P and particle velocity V – to infill the ghost notch (Tenghamn et al., 2007; Robertsson et al., 2008). This latter class of acquisition and processing techniques benefit from an increased low-frequency contribution from hydrophone data enabled by a consistent, deep tow across all offsets. However, a key challenge is the effective use of the velocity measurements at low frequencies caused by the increased noise contamination in this frequency range.

This paper summarizes a 3D seismic survey acquired using a multimeasurement towed streamer based on microelectrical mechanical system (MEMS) accelerometers to record point-receiver, full-bandwidth particle acceleration. After initial data preconditioning, this system can provide P and vertical particle velocity \( V_z \) input to an appropriate receiver deghosting algorithm, utilizing the velocity derived from the acceleration measured by the MEMS accelerometers. The images shown in this paper are based on the results obtained using the optimal deghosting (ODG) technique described by Caprioli et al. (2012), which is a variation of the Posthumus (1993) deghosting method developed for over/under towed streamers. ODG incorporates an additional scheme to weight the contributions of P and \( V_z \) data based on their respective ghost models and noise characteristics. Due to the coarse crossline sampling in conventional streamer acquisition, the ODG technique assumes 2D propagation along streamers; however, the results demonstrate that this provides a high-fidelity, broadband dataset fit for purpose for the survey objectives. Once the P and \( V_z \) data are combined the data are processed as a conventional dataset.

Geologic setting, survey objectives, and legacy data

The prospect area is situated offshore West Africa, in an area of significant geologic complexity. The water depth is relatively shallow at approximately 170m. The tertiary near-surface sequences exhibit extensive shallow channeling. This is followed by a chaotic zone on the seismic data that is associated with rapid deltaic deposition, and expected to contain similar channeling, but at smaller scales. The primary zone of interest lies beneath an unconformity which separates the overburden from an underlying elongated half-graben structure, that is Lower Cretaceous–Triassic in age, lacustrine in origin, and filled with sand and shale sequences. Listric faults define the half-graben from the underlying rocks, which were perceived as undifferentiated basement on the legacy seismic data.

The objectives of the survey are to image structural and stratigraphic traps to improve confidence in well positioning and prospect identification. High-resolution, high-quality broadband 3D seismic data are considered essential to improve confidence in well positioning, driven by the need to delineate terraces, pinch-outs, and small-scale faulting at the reservoir level. Dips in the sedimentary formations reach 25°; however, faults of up to 50° must be imaged, and there is evidence of complex and overhanging structures in places.

The prospect was recently defined by interpretation of multivintage 2D seismic lines acquired in the 1980s and late 1990s (and reprocessed in 2008), and log data from an exploration well acquired in the late 1980s. Aside from the 2D geometry, limitations of the legacy data included strong multiple contamination plus lack of low frequencies and continuity for reliable amplitude inversion, and are subsequently unsuitable for prospect development.
Multimeasurement streamer acquisition for reservoir development

After early single-sensor noise attenuation, designature, and wavefield separation of the P and Vz data using ODG, the remaining processing sequence included the following stages:

**Demultiple:** Successful pre-migration attenuation of the multiples that contaminate this dataset was achieved using a combination of true-azimuth 3D surface multiple prediction, deterministic water-layer demultiple (DWD), and weighted least-squares Radon. Using an appropriate crossline aperture, the predicted surface multiple model was adapted simultaneously with the predicted multiple model from DWD, and subtracted from the input data. Weighted least-squares Radon was subsequently applied to further suppress residual multiple energy that had survived this combined application.

**Imaging and dense velocity analysis:** The fully processed pre-migrated data were split into 60 offset groups,
Multimeasurement streamer acquisition for reservoir development

regularized and cell centred. The offsets were then time-migrated using the Kirchhoff algorithm. Due to the rapid lateral variation in the velocity profile from the basement high to the graben structure, a very detailed post migration stacking velocity field was derived to provide the best stack response and to ensure that a pass of weighted least-squares Radon worked to best effect. This velocity field was determined on a grid spacing of 125 x 125 m, followed by residual automatic velocity analysis at every common midpoint (12.5 x 12.5 m).

Results and preliminary interpretation

Figure 1 compares the 2D legacy and ODG images from a crossline migrated section from the 3D volume. As expected, the new 3D data set provides significant uplift over the legacy data. The previously undifferentiated basement now becomes resolved, with evidence of layering and both small- and large-scale faulting around the edges of the half-graben, and with clear reflections in the basement that may indicate the presence of intrusive and extrusive volcanics. More details are revealed within the basin, indicating a rapid depositional environment during the early fill, but slowing and becoming more consolidated higher in the graben, with small-scale onlapping events. This suggests the formation of potential source rocks early in the rifting process, with a decrease in acoustic impedance (white trough) indicating higher organic content and varying thickness in both directions as a function of basin depth at time of fill. There is also evidence of significantly more structural complexity around the graben edges, with the potential for rapid lateral velocity variations.

Figure 2 compares an unmigrated stack of the ODG data versus equivalent stacks of the separate P and V\textsubscript{z} inputs. Figure 4 replicates these displays but with an additional 10-Hz high-cut filter applied. As expected, the V\textsubscript{z} stack exhibits stronger noise contamination; however, it also demonstrates the V\textsubscript{z} signal content contributing to the deghosting and wavefield separation step at frequencies below 10 Hz.

Figure 3 compares an unmigrated stack of the ODG data versus equivalent stacks of the separate P and V\textsubscript{z} inputs. Figure 4 replicates these displays but with an additional 10-Hz high-cut filter applied. As expected, the V\textsubscript{z} stack exhibits stronger noise contamination; however, it also demonstrates the V\textsubscript{z} signal content contributing to the deghosting and wavefield separation step at frequencies below 10 Hz.

Preliminary interpretation indicates that a wealth of geologic information is present in the broadband data set at all depths, encompassing overburden, reservoir and source-rock levels. Figure 5 is one example of a shallow image that illustrates the complex environment of sinuous overlapping channels, erosional surfaces, and faulting across the whole area. Small-scale structural and lithological features are well defined, despite the relatively wide 100-m streamer separation.

Conclusions

Multimeasurement 3D towed-streamer seismic data were acquired and processed through a prestack time-migrated sequence including wavefield separation and receiver deghosting of the P and V\textsubscript{z} measurements using an ODG technique. The acquisition benefited from the low-frequency enhancement of a multisensor streamer towed at a depth of 23 m across the full offset range. Further uplift in low-frequency content would be expected from residual source-side deghosting. Early point-receiver processing on the accelerometer data also provided noise suppression to enable contribution from the V\textsubscript{z} data to the deghosting at frequencies below 10 Hz. Preliminary interpretation on the final volumes indicates a high-resolution, temporally broadband data set, for input to detailed interpretation and quantitative amplitude inversion.

Acknowledgements

The authors thank Schlumberger for permission to publish this work and Trevor Ridley for his endorsement. Clara Abu, Malcolm Francis, Camille Arrii, Clark Chahine, and Pete Watterson from Schlumberger for their contributions.
Multimeasurement streamer acquisition for reservoir development

Figure 3: Unmigrated stack section comparing (a) receiver deghosted ODG output with (b) P and (c) $V_z$ input data.

Figure 4: Repeat of Figure 3 with 10 Hz high-cut filter applied.

Figure 5: (a) time slice extracted from an interpreted horizon in the shallow tertiary section, and (b) redisplayed using a color blend of frequency envelopes to enhance the geologic information.
EDITED REFERENCES
Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2014 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES


